Studies on the Particle Boards : Report 6: Effects of Resin Content and Particle Dimension on the Physical and Mechanical Properties of Low-density Particle Boards

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Report 6 : Effects of Resin Content and Particle Dimension on the Physical and Mechanical Properties of Low-density Particle Boards

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木本　馨・石森英次・佐々木光・満久崇麿：パーティクル・ボードに関する研究（第6報）含脂率およびパーティクル・ディメンションが低比重ボードの材質におよぼす影響について

I Introduction

It should be regarded as important for potential uses that low-density particle boards have a higher degree of dimensional stability as well as high-density particle boards.[1] Some researches have been conducted in recent years on the properties of low-density particle boards made from many different particles,[2)3)] but many and more data for these boards must be required to increase the range of their use.

Present study was undertaken to ascertain optimum factorial combination of resin content and particle dimension for the development of optimum properties of low-density particle boards.

II Experimental Procedure

1. **Board Fabrication**

(a) Particle Preparation

Wood particles used in this study are divided into two followinng series.

Series A : Particles which were crushed in a hammermill, of lauan (*Shorea*) rotary veneer of 0.9 mm thick. They were sifted out and divided into three classes as follows.

A-1 : coarse particles (Photo. 1).

A-2 : medium coarse particles (Photo. 2).

A-3 : fine particles (Photo. 3).

Average dimension of these particles are shown in Table 1.

Series B : Lauan particles which had comparatively high ratio of width-to-thickness. They were composed of three following classes.

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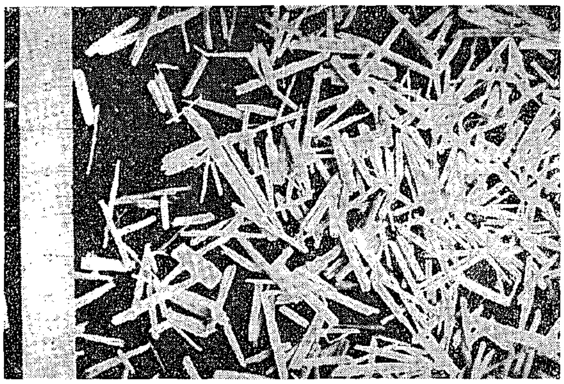

Photo. 1. Coarse needle-like particle (A-1).

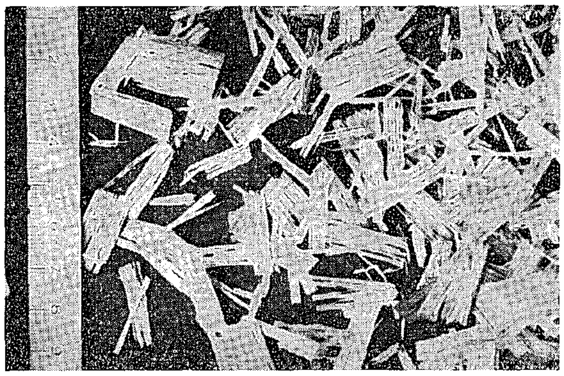

Photo. 4. Coarse flakes (B-1).

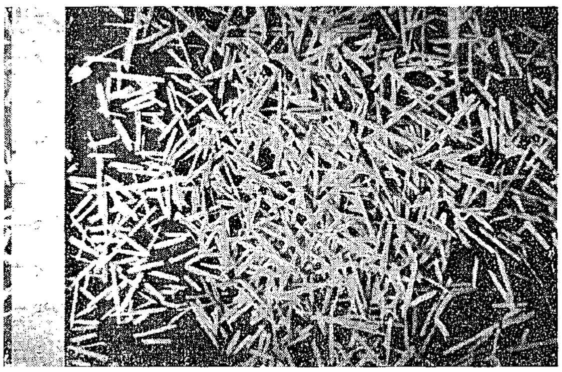

Photo. 2. Medium coarse needle-like particle (A-2).

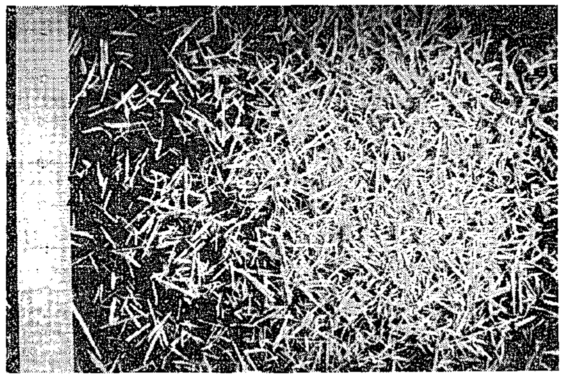

Photo. 5. Medium coarse flakes (B-2).

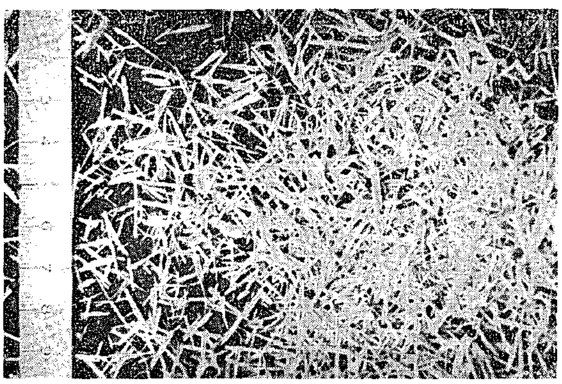

Photo. 3. Fine needle-like particle (A-3).

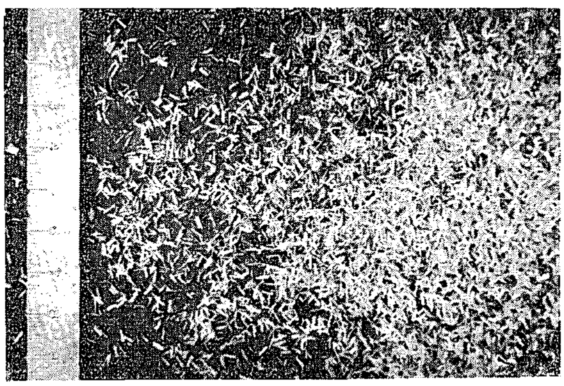

Photo. 6. Cross-cut saw dust (B-3).

Table 1. Particle dimension, series A.

	t (cm)	l (cm)	b (cm)	l/t
A-1	0.088±0.034	2.172±0.784	0.179±0.073	25
A-2	0.084±0.021	1.433±0.625	0.135±0.058	17
A-3	0.041±0.025	0.641±0.325	0.068±0.032	16

Table 2. Particle dimension, series B.

	t (cm)	l (cm)	b (cm)	l/t
B-1	0.021±0.009	2.0 ±0.2	0.79 ±0.34	100
B-2	0.021±0.009	1.0 ±0.9	0.08 ±0.03	50
B-3	0.019±0.012	0.19±0.08	0.019±0.012	10

B-1 : coarse flakes (Photo. 4).

B-2 : medium coarse flakes crushed in a hammermill, of above flakes (Photo. 5).

B-3 : cross-cut saw dust (Photo. 6).

Average dimension of these particles are shown in Table 2.

(b) Resin Binder Application

One of commercial urea resin liquid adhesives was used in this study. After particles mentioned above were dried to 8~9 percent moisture content, each of 8, 10 and 15 percent resin solids based on air-dried weight of particles was applied. The adhesives had a solid conten of 50 percent, and were applied to the particle in fine spray.

(c) Pressing

Resin applied particles were dried to 15~18 percent moisture content, and then scattered into the particle mat of 30×30 cm. Steel stops of 1.2 cm thick were placed between the 2 mm thick aluminum cauls to control the thickness of the board. The press conditions were as follows.

Consolidating pressure	5~10 kg/cm^2
Press temperature	130°C
Pressing time	18 min

Six types of particles (two series) were incorporated in the experiment together with 3 levels of resin content. This combination of variables provided an experiment having 6×3 factorial design. Two replications of each treatment combination were employed.

2 Specimen Preparation and Testing

The boards were conditioned in a room for about a week and then they were trimmed and cut into the required test specimens. The following tests were carried out.

The static bending test and the screw withdrawal test were carried out according to the JIS* (A 5908). The static bending test specimens were 5 cm in width and 18 cm in length, and screw withdrawal test specimens were 5×5 cm.

* Japanese Industrial Standard.

The internal bond test was carried out according to ASTM (D 1037--52T). The internal bond test specimens were 5×5 cm. These specimens were glued between aluminum holding blocks.

Dimensional stability was measured by determining the percent change in weight and thickness. Specimens for the water absorption test and thickness expansion test were 7×7 cm. The specimens were submerged vertically in water maintained at a temperature of 20±1°C. After 2-hr and 24-hr-submersion, the specimens were suspended to drain for 10 min, at the end of which time the excess surface water was removed and the thickness and weight of the specimens were measured.

Specimens for the water vapor adsorption test and accompanying thickness expansion test were 5×5 cm. These were first brought to equilibrium moisture content of about 10 percent by placing them in a controlled desiccator for 1 month. Every ten of them were placed vertically in another desiccator of 30 cm diameter saturated with water vapor and maintained at a temperature of 30±1°C, and after 24 hr changes of the thickness and weight of the specimens were measured. These dimensional properties were evaluated by the following formulas.

$$\begin{array}{l}\text{percent water absorption and}\\ \text{water vapor adsorption}\end{array} = \frac{(\text{final weight}) - (\text{initial weight})}{\text{inital weight}} \times 100 (\%)$$

$$\text{percent thickness expansion} = \frac{(\text{final thickness}) - (\text{initial thickness})}{\text{initial thickness}} \times 100\ (\%)$$

Specimens for testing the moisture content and the specific gravity of boards were cut from the sound part of both end of the specimen after the bending test. They were about 5×5 cm. The specific gravity was computed from the dimensions and weight of the air dried specimen.

III Results and Discussion

The average values and the standard deviations of the physical and mechanical properties of the low-density particle boards for each particle dimension and resin content are summarized in Table 3.

An analysis of variance was performed with the data represented in Table 3 to test the significance of the effect on board properties of resin content, particle dimension and their interaction, if any. Results of analysis for particle series A (needle-like) and for particle series B (flaky) are shown in Tables 4 and 5, respectively. These tables show that resin content and particle dimension have significant effects on most of the board properties. And interaction of resin content and particle dimension has also significant effects on some properties of board. This means that each resin content and perticle dimension is not inde-

Table 3. Physical and mechanical properties of the particle boards.

Particle series*	Particle dimension*	Resin content (%)	Specific gravity	Moisture content (%)	Modulus of rupture (kg/cm²)	Screw withdrawal load (kg)	Internal bond strength (kg/cm²)	Percent water absorption		Percent thickness expansion in water absorption		Percent water vapor adsorption	Percent thickness expansion in water vapor adsorption
								2-hr	24-hr	2-hr	24-hr		
A	A-1	8	0.35(0.02)**	12.5(0.8)	32.7(3.98)	16.1(3.22)	1.45(0.37)	7.7(2.69)	113.0(5.68)	9.3(1.38)	13.7(2.55)	5.7(1.04)	5.1(1.81)
		10	0.34(0.02)	12.1(0.9)	42.7(6.96)	20.7(6.59)	3.13(0.18)	66.1(4.60)	107.4(13.50)	5.6(0.61)	8.2(1.62)	7.1(1.42)	4.3(1.92)
		15	0.34(0.02)	12.0(1.9)	48.4(7.79)	17.0(6.14)	3.37(0.76)	50.7(3.14)	102.2(13.29)	4.4(0.47)	7.0(0.98)	5.5(0.64)	1.9(0.63)
	A-2	8	0.33(0.02)	10.5(2.0)	30.1(5.24)	11.9(2.40)	1.61(0.24)	107.1(8.04)	134.4(3.20)	8.0(0.75)	10.2(1.59)	6.3(1.06)	3.8(1.62)
		10	0.35(0.02)	12.4(0.9)	41.4(7.49)	15.8(2.29)	2.93(0.24)	91.5(7.07)	120.8(6.41)	5.0(0.51)	7.6(1.07)	6.9(1.02)	3.1(0.86)
		15	0.37(0.01)	11.9(0.8)	51.0(7.02)	16.9(2.99)	2.95(0.32)	86.6(3.13)	108.6(5.84)	4.9(0.36)	6.1(0.37)	6.7(1.15)	3.1(0.49)
	A-3	8	0.34(0.01)	12.8(0.9)	29.1(4.50)	10.7(1.17)	1.57(0.33)	130.8(8.50)	154.7(9.04)	5.6(1.39)	7.6(2.19)	8.6(0.52)	5.4(0.59)
		10	0.34(0.03)	12.5(1.2)	25.0(2.34)	12.5(3.00)	2.43(0.60)	120.9(12.29)	149.0(12.88)	4.7(0.53)	6.4(1.58)	8.4(0.71)	3.5(0.45)
		15	0.31(0.02)	12.5(0.6)	21.9(7.44)	9.9(1.79)	1.86(0.30)	138.0(5.48)	173.4(10.90)	3.4(0.58)	4.6(0.97)	6.8(2.13)	3.3(1.16)
B	B-1	8	0.40(0.02)	9.6(0.1)	78.0(24.13)	14.4(3.97)	0.86(0.26)	39.4(6.17)	87.9(13.15)	2.0(0.64)	6.4(0.57)	5.0(0.60)	5.0(0.87)
		10	0.42(0.01)	9.4(0.1)	92.5(11.31)	15.8(2.78)	1.32(0.34)	28.9(4.37)	65.5(8.74)	2.0(0.45)	5.3(0.51)	3.7(0.10)	3.7(0.45)
		15	0.43(0.01)	8.6(0.1)	98.0(14.88)	16.9(1.46)	1.64(0.60)	26.9(3.89)	71.5(8.54)	1.6(0.22)	4.9(0.48)	4.1(0.56)	4.1(0.81)
	B-2	8	0.39(0.02)	9.7(0.1)	50.2(10.69)	13.0(2.12)	2.01(0.27)	66.3(16.18)	125.9(13.25)	3.5(0.58)	9.8(1.09)	4.2(0.28)	4.2(0.55)
		10	0.40(0.02)	9.2(0.4)	61.8(13.78)	15.8(1.35)	1.45(0.27)	32.1(6.86)	105.6(18.62)	4.5(1.42)	8.7(1.13)	4.1(0.47)	4.1(0.41)
		15	0.42(0.02)	9.0(0.4)	83.0(7.72)	18.1(3.26)	3.52(0.25)	39.3(4.53)	80.6(10.78)	2.6(0.28)	6.3(0.60)	4.1(1.10)	4.1(0.68)
	B-3	8	0.40(0.01)	8.6(0.1)	24.1(3.67)	9.4(1.58)	1.94(0.15)	21.3(1.57)	57.4(7.66)	2.9(0.18)	7.1(0.33)	3.8(0.36)	3.8(0.48)
		10	0.42(0.02)	8.6(0.1)	32.6(6.16)	11.5(1.68)	2.26(0.30)	21.2(4.07)	48.7(9.63)	3.0(0.40)	6.4(0.30)	3.8(0.42)	3.8(0.46)
		15	0.44(0.01)	8.5(0.3)	48.1(4.09)	16.5(1.34)	4.42(0.98)	18.3(2.28)	40.6(13.80)	2.3(0.18)	5.1(0.30)	3.8(0.50)	3.8(0.35)

*) cf. Table 1 and 2.

**) number in parentheses means the standard deviation.

Table 4. Analysis of variance of properties of low-density particle board (particle series A).

	Main effects		Two-factor interactions
	Resin content	Particle dimension	
Modulus of rupture	0.01	0.01	0.01
Screw withdrawal	N.S.	0.01	N.S.
Internal bond	0.01	0.01	0.01
Water absorption 2-hr	N.S.	0.01	0.01
24-hr	N.S.	0.01	0.01
Thickness change (in water abs.) 2-hr	0.01	0.01	0.05
24-hr	0.01	0.01	0.05
Water-vapor adsorption 24-hr	0.05	0.01	N.S.
Thickness change (in water-vapor ads.) 24-hr	0.01	N.S.	N.S.

0.01—Significant at 1 percent level of probability.
0.05—Significant at 5 percent level of probability.
N.S.—Not significant at 5 percent level of probability.

Table 5. Aanalysis of variance of properties of low-density particle board (particle series B).

	Main effects		Two-factor interactions
	Resin content	Particle dimension	
Modulus of rupture	0.01	0.01	N.S.
Screw withdrawal	0.01	0.01	0.05
Internal bond	0.01	0.01	0.01
Water absorption 2-hr	0.01	0.01	0.01
24-hr	0.01	0.01	0.05
Thickness change (in water abs.) 2-hr	0.01	0.01	N.S.
24-hr	0.01	0.01	0.05
Water-vapor adsorption 24-hr	0.05	0.01	0.05
Thickness change (in water-vapor ads.) 24-hr	N.S.	N.S.	N.S.

0.01—Significant at 1 percent level of probability.
0.05—Significant at 5 percent level of probability.
N.S.—Not significant at 5 percent level of probability.

pendent factors for the board properties.

In order to discuss minutely the effects of the factors, the statistical comparison was made[6)7)] between any two resin contents or particle dimensions. The result of these comparison is shown in Fig. 1 to 9 with variables of resin content. In these figures, lines parallel to the abscissa indicate that no significant difference was brought out between the two resin contents, and sloping lines indicate the significant difference.

As the board with particles of series A (needle-like) differed a little from board with particles of series B (flaky) in density and moisture content (Table 3), it is not reasonable that the physical and mechanical properties of these two groups of boards should be compared directly with each other and the difference be discussed. In this study, therefore, discussion was developed to the two groups of boards separately.

1. Modulus of Rupture (Fig. 1)

In boards made from particles of series A (needle-like), there was no significant difference of modulus of rupture in particle dimensions at a resin content of 8 percent, but at 10 and 15 percent resin content, boards from the medium (A-2) and the coarse particles (A-1) show higher modulus of rupture, and the values at 10 percent resin content did not differ from those at 15 percent. But, in boards containing particles series B (flaky), increase of resin content or particle dimension can be expected to improve bending strength and the effect of resin content is not so notable as in that of particle dimension.

Many papers[1,3,8,9,10,11] reported that in medium-density particle board, higher modulus of rupture occurred at higher resin content and larger particle dimension, and they tried to explain it reasonably. In this study, the fact that the coarse needle-like particles were not always advantageous for modulus of rupture of board may be results of higher local compression stresses and accompanying

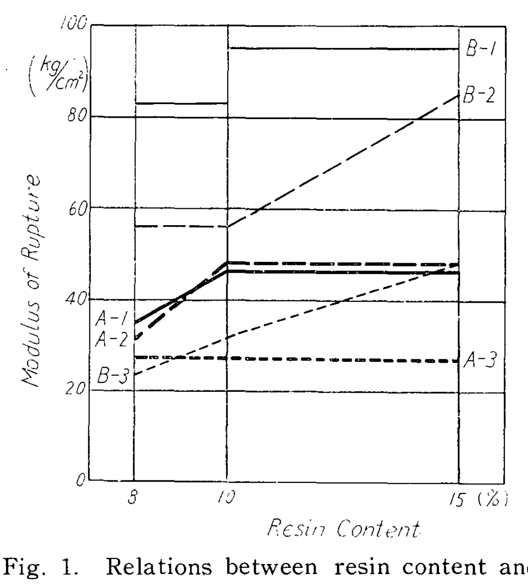

Fig. 1. Relations between resin content and modulus of rupture.

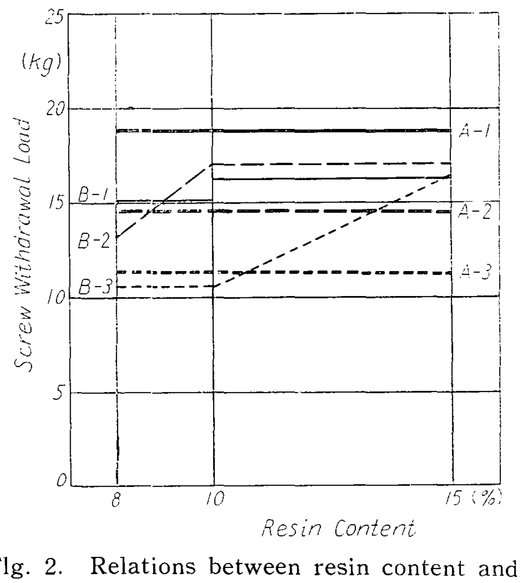

Fig. 2. Relations between resin content and screw withdrawal load.

compression deformations for a density on the thicker particles.

2. **Screw Withdrawal** (Fig. 2)

In boards of series A (needle-like), there was no significant difference in screw withdrawal resistance among boards of three different resin contents. But an increase of screw withdrawal resistance of boards with particle dimension was apparent. As for the boards of series B (flaky), increase of resin content and particle dimension can be expected to improve slightly the screw withdrawal resistance except for smaller screw withdrawal resistance of boards from saw dust (B-3) at 8 and 10 percent resin content.

In boards from needle-like particles (series A), larger screw withdrawal resistance of boards from coarse particles can be explained by existence of moderately large void spaces advantageous for screwing. Resin content is one of the most important factors affect the screw withdrawal resistance of saw-dust board, and the remarkably small withdrawal resistance at 8 and 10 percent resin content seems to result from the weakness of mutual bond of particles.

3. **Internal Bond** (Fig. 3)

In particle series A (needle-like), internal bond strength increased with increasing resin content, but it was not affected by resin content above 10 percent. The effect of resin content on internal bond of boards from series B, however, was very complicated and interacted with particle dimensions. But, on the whole, the bond strength rather increased with increasing resin content.

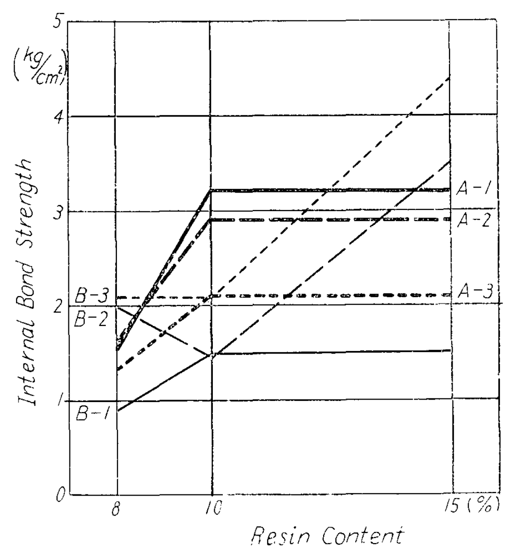

Fig. 3. Relations between resin content and internal bond strength.

Relation between particle dimension and internal bond strength was very different in the two types of the boards. Although the increase of dimension of needle-like particles can be expected to improve the bond strength, but inversely in flaky particles the bond strength decreases with increasing particle dimensions.

It was difficult to guess the cause of the results mentioned above, and the discussion should be developed to factors such as contact of the particle interface, resin coverage, mechanical properties of particles, orientation or bridge effect of particles, discontinuity of void spaces, and their complexed combinations.

4. **Water Absorption** (Figs. 4, 5)

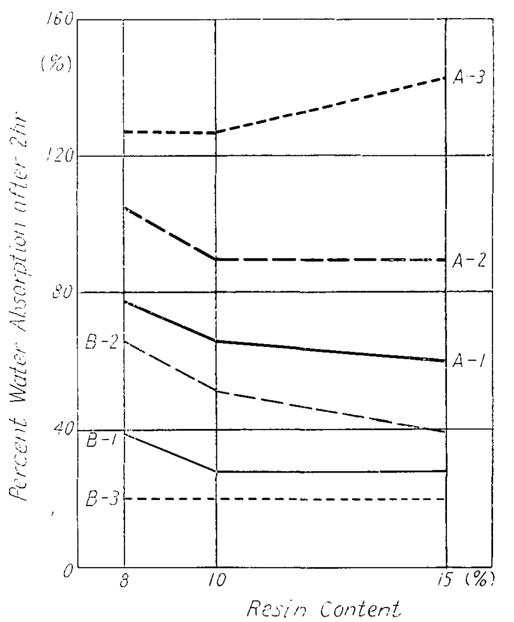

Fig. 4. Relations between resin content and percent water absorption after 2 hr.

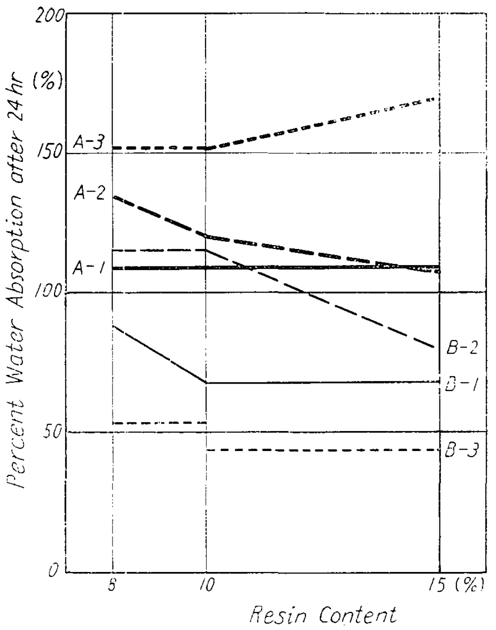

Fig. 5. Relations between resin content and percent water absorption after 24 hr.

Percent water absorption of boards from fine needle-like particles (A-3) increased with increasing resin content above 10 percent resin content, and that from the other particles decreased slightly with increasing resin content, if present. On the whole, smaller percent water absorption occurred at larger particle dimension except for that of saw-dust boards. Why percent water absorption of saw-dust boards was exceptionally small, can not be explained reasonably. But it may be related to the discontinuity of void spaces in saw-dust boards.

In comparing Fig. 4 with Fig. 5, percent water absorption of boards from needle-like particles after 2-hr soaking was about 60 to 85 percent of that of 24-hr soaking, but percent water absorption of boards from flaky particles after 2-hr soaking was only 35 to 60 percent of that of 24-hr soaking. These differences in the rate of water absorption seem to result from the fact that the void spaces in boards acted mainly on initial water absorption of boards.

5. Thickness Expansion in Water Absorption (Fig. 6, Fig. 7)

On the whole, increase of resin content can be expected to improve the thickness stability of board in water soaking, especially in boards from the coarse particles of series A (needle-like). At 8 percent resin content, boards from needle-like particles of A-1 and A-2 developed significantly greater thickness expansion than boards from the particle A-3, which is contrary to the results of Fig. 4 and 5. This could be results of springback from higher com-

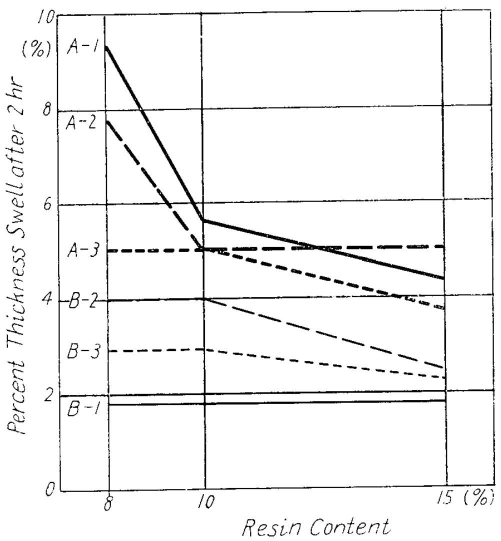

Fig. 6. Relations between resin content and percent thickness swell after 2 hr.

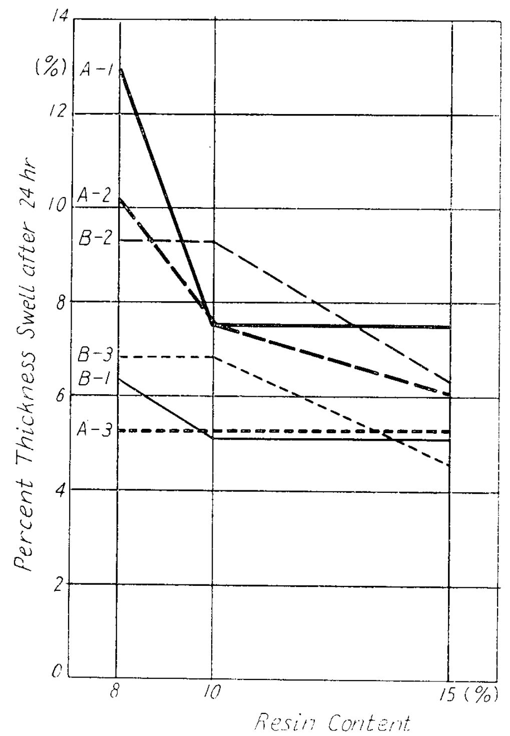

Fig. 7. Relations between resin content and percent thickness swell after 24 hr.

pression stress and accompanying compression deformation for a given density on the thicker particles. Swell of saw-dust boards was comparatively large for its small percent water absorption, and the thickness stability of boards containing the coarse flakes (B-1) was excellent. This may be attributed to the difference in the resin coverage on these particles.

In comparing Fig. 6 with Fig. 7, percent thickness expansion of boards from needle-like particles after 2-hr soaking was about 65 to 95 percent of that of 24-hr soaking, and in board B-3 they were almost equal. But, percent thickness expansion of flake boards after 2-hr soaking was less than half of that of 24-hr soaking. Such difference in swelling rate between the two series of boards seems to result from the fact that the rate of penetrating water into boards is higher in needle-like particle boards than in flake boards.

6. Water Vapor Adsorption (Fig. 8)

In boards produced from needle-like particles, influences of resin content on water vapor adsorption was small if present, but percent water vapor adsorption decreased slightly with increasing particle dimensions. This slight decrease may be attributed to the decreased internal surface for adsorption of larger particles. On the other hand, water vapor adsorption of flake boards was small and hardly influenced by either resin content or particle dimension. It may be

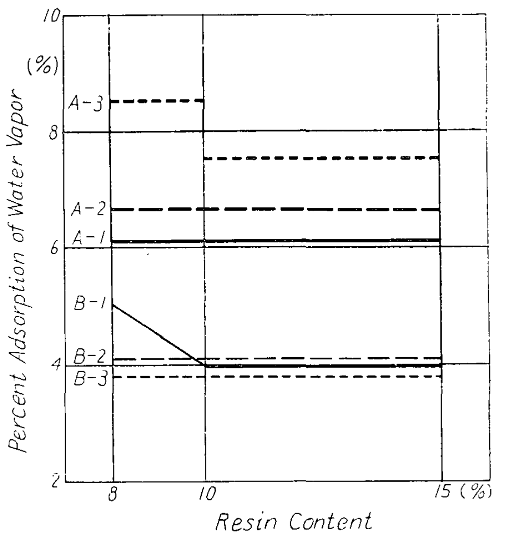

Fig. 8. Relations between resin content and percent adsorption of water vapor.

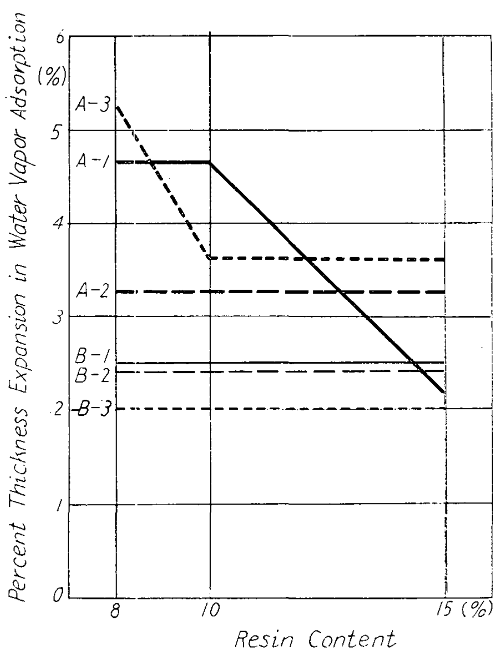

Fig. 9. Relations between resin content and percent thickness expansion in water vapor adsorption.

due to the greater degree of internal discontinuity of void spaces and the faint adsorption on their internal surfaces.

7. Thickness Expansion in Water Vapor Adsorption (Fig. 9)

In boards containing needle-like particles, increase of resin content can be expected to improve thickness stability in water vapor adsorption except for board with A-2 particles. This tendency was difficult to illustrate, but it may be the complex of many factors such as resin coverage of particles, stiffness of particles, pressure necessary to form different particles into boards of a given density, and these interactions. Increase of resin content and particle dimension in flake boards can be hardly expected to improve the thickness stability in water vapor adsorption (statistically insignificant). This can be attributed to the faint adsorption of water vapor on the internal surfaces of these boards as mentioned in above section.

The effects of resin content and particle dimension on some properties of low-density boards have been discussed in seven sections presented above. But, still more, it is necessary to discuss also from some different points of view.

First, because the resin content presented in this paper was calculated with weight of resin solids per particle weight, resin spread per unit surface area of particles increases consequently with increasing particle dimension. Those relations in this study are as shown in Table 6. Thus, increase of particle dimension can be expected to improve the bonding of the particle innerface, which results

Table 6. Resin spread on the different particles.

Particle series	Particle tipes	Comparative values of resin spread on an unit surface of the particles
A	(A−1) : (A−2) : (A−3)	≒ 5 : 4 : 2
B	(B−1) : (B−2) : (B−3)	≒ 5 : 4 : 2

in better properties of boards.

KITAHARA[12] reported the decrease of mechanical properties of boards with increasing particle dimension at the constant resin spread. And POST[13][14] showed, also, at constant resin spread, the increase of mechanical properties of boards with increasing length and width of particles and with decreasing thickness of particles.

Meanwhile, to keep resin content constant is important from the manufacturing view point and in such a case length-to-thickness ratios of particles l/t have been accepted as a good index for the properties of particle boards. They, of course, merely reflect the combined effects of length and thickness, but are useful in determining at what point these factors reach a maximum and level off. The l/t ratios in this study are as shown in Tables 1 and 2.

In Table 1, the l/t ratio differs little among particles of A-1, A-2, and A-3, and it is not a reasonable index for estimating properties of boards from needle-like particles. But, in flakes l/t ratio varies from 10 (B-3) to 100 (B-1). Fig. 10 show the composite curves of l/t ratio vs. each of the seven properties measured in this study. In this figure, the curves were shown only for resin content of 10 percent, because the slopes of the curves were the same for all of the three resin contents included in this study.

Modulus of rupture increased as the l/t ratio increased, and it could not determine at what point the effect reached a maximum and leveled off. Screw withdrawal load in-

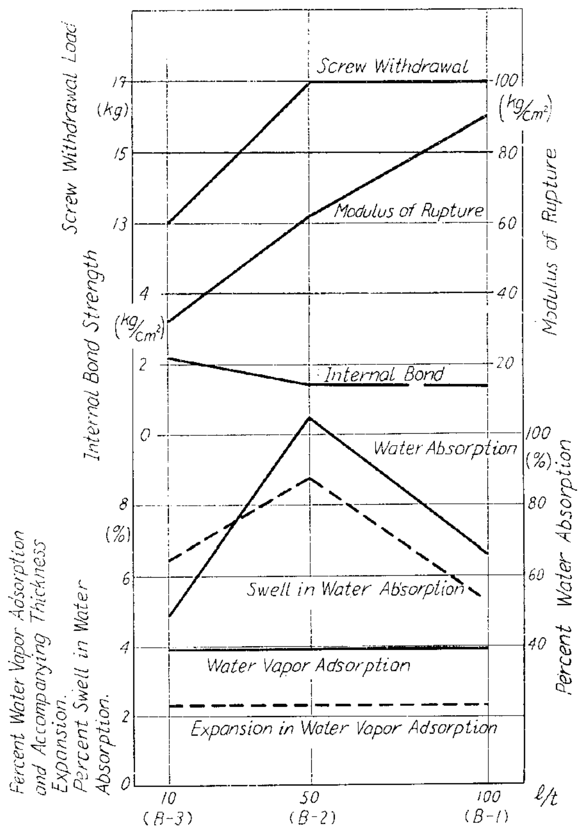

Fig. 10. Composite curves of length-to-thickness ratio for each of seven properties of lauan flake boards.

creased also with increasing the l/t ratios, but the curve reached a maximum and leveled off at an l/t of 50. Internal bond strength decreased as the ratio increased until a ratio of 50 was reached, at which point the curve leveled off and no change occurred withg increasin ratio of l/t. Water vapor adsorption and accompanying thickness expansion was not changed with increasing ratio of l/t. Water absorption and accompanying thickness swell reached a maximum at an l/t of 50. This is not similar to that which has been reported[8], and the reason why is very difficult to illustrate.

Summary

Low-density particle boards (specific gravity, about 0.4) were produced from each of three kinds of lauan needle-like particles (Table 1, Photos. 1~3) and three kinds of lauan flakes (Table 2, Photos. 4~6), applying a commercial urea resin adhesive at 8, 10, and 15 percent resin solids. Then the physical and mechanical properties were tested and the data were discussed statistically to clarify the effects of particle dimension and resin content on those properties.

The results are summarized as follows.

1) Increase of particle dimension and resin content can be expected to improve modulus of rupture of boards, especially in flake types (Fig. 1).

2) Screw withdrawal resistance incraesed with increasing particle dimension, but the influence of resin content was very small, if present (Fig. 2).

3) Internal bond strength increased with increasing particle dimension in needle-like particle, but in flake type board it decreased with increasing particle dimension. On the other hand, there was a slight improvement of internal bond with increasing resin content (Fig. 3).

4) With a few exception, slight decrease of water absorption and accompanying thickness swell can be expected with increasing particle dimension and resin content (Figs. 4~7).

5) Influence of particle dimension and resin content on water vapor adsorption and accompanying thickness expansion was very small, if present (Figs. 8, 9).

摘　　要

Table 1 と Photos. 1~3 に示すような3種類の荒さのラワンの針状パーティクルおよび Table 2 と Photos. 4~6 に示すような3種類の荒さのラワンのフレーク状パーティクルを用い，市販の尿素樹脂接着剤を固形分にして8, 10, および15%添加して，比重約0.4の低比重パーティクル・ボードを作り，それらの材質を試験して，推計学的にボードの材質におよぼすパーティクル・ディメンションおよび含脂率の影響を検討した。結果を要約すると次のごとくである。

(1) 曲げ破壊係数は含脂率ならびにパーティクル・ディメンションの増加に伴なつて上昇し，この傾向はとくにフレーク状パーティクルにおいて著しい (Fig. 1)。

(2) 木ねじ保持力はパーティクル・ディメンションの増加とともに増すが，含脂率にはあまり影響されない (Fig. 2)。

(3) 剥離抵抗は針状パーティクルではパーティクル・ディメンションが増すと増加するが，フレーク状パーティクルではパーティクル・ディメンションが増すと逆に減少する。また含脂率が増すと剥離抵抗は幾分増加するようである (Fig. 3)。

(4) 一部の例外を除けば，吸水率とそれに伴なう厚さの膨脹率は含脂率およびパーティクル・ディメンションが増せば幾分低下する傾向がある (Figs. 4~7)。

(5) 吸湿率とそれに伴なう厚さの膨脹率は含脂率およびパーティクル・ディメンションによつてあまり強く影響されない (Figs. 8, 9)。

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